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Original Research

Diesel to Solar Irrigation System: Economic, Environmental, and Social Acceptability Analyses by Small-Scale Farmers of Calapan, Oriental Mindoro

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Abstract

Solar irrigation systems are sustainable practices that can improve local communities' well-being and enhance agriculture's resilience to climate change while reducing environmental impacts. Due to its high investment cost, small-scale farmers are inclined to use traditional fossil-based irrigation systems that can harm humans and the environment. This study analyzes the environmental impacts, economic feasibility, and social acceptability of shifting agricultural practices from diesel-fueled to solar irrigation systems. Taking the perspective of small-scale farmers from Calapan City, Oriental Mindoro, results found that solar irrigation system systems have initial investment but lower maintenance and operational costs. These resulted in an attractive economic feasibility of the project with PHP 19,693 of fuel cost savings per hectare per year, a project net present value of PHP 10,214 per hectare, a payback period of 8.27 years, and returns on investment at 110%. Additionally, shifting to a solar irrigation system significantly reduces the greenhouse gas emissions from diesel at 199.78 CO_2 eq/ha/yr, and avoids air pollutant emissions at 14.91 g/ha/yr particulate matter, 2.98 g/ha/yr nitrogen oxides,193.82 g/ha/yr sulfur oxides, and 149.09 g/ha/yr carbon monoxide. Despite the lack of in-depth environmental awareness, small-scale farmers are interested in investing in solar irrigation systems with 68% social acceptability. Results provide bases for recommendations on promoting more human ecologically and sustainable agriculture irrigation systems in the Philippines and other developing countries.

Keywords— *climate change mitigation, GHG emission reduction, renewable energy, small-scale farming, solar irrigation, sustainable agriculture*

1 Introduction

The global concern for greenhouse gas (GHG) emissions from the agriculture-economic sector continues to rise. In a report by the Intergovernmental Panel on Climate Change 2014 [1], 24% of the global GHG emissions came from agriculture, forestry, and land use. In response, 197 countries adopted the Global Climate Agreement at the Paris Climate Conference in 2015 to set a universal action plan to limit global warming below 2°C. However, implementing sectoral actions in compliance with this limit poses major food security and agriculture challenges. Data shows that rice farming alone yields high levels of GHG emissions due to production, consumption, and transportation systems [1]. This further intensifies as farmers put excessive pressure on rice fields to feed the world's increasing population [2]. Hence, the efforts to limit global warming may also curb food productivity, eventually leading to hunger and poverty [3]. For this reason, studies on sustainable farming considerably help identify opportunities for reducing emissions while addressing food security, resilience, and rural development goals.

In a meta-analysis of various studies citing practices that can alleviate the increasing production of GHG in agriculture, the water management option is listed as one of the promising solutions [4]. However, even with the arrival of solar photovoltaic irrigation systems in the Philippines, most farmers still rely on diesel-powered irrigation pumps. The combustion of diesel produces higher GHG emissions compared to other types of fuels [5]. Its emissions also include pollutants associated with health effects, particularly cardiovascular and pulmonary diseases [6]. With the combined impacts from environmental and health risks of using diesel-powered combustion engines such as the ones used in irrigation pumps, the transition to a greener energy source in the agricultural sector is highly called for.

In the interest of fairness, the administration led by the Department of Agriculture (DA), Philippine Rice Research Institute (PhilRice), and National Irrigation Administration (NIA) have ongoing and future projects for the rice farming industry. As reflected in PhilRice's strategic plan for 2017-2022, there are several technological innovations that they aim to achieve for continuing sources of growth. This includes advanced water resources management, among others. In addition, DA and NIA have several large solar irrigation projects already installed in different parts of the country. In Rizal, a PHP 5.2-million solar irrigation project was installed in 2018, while in Laguna, two solar-powered irrigation pumps worth 1.2 million and 5.8 million pesos were installed in 2019 which can irrigate 8 hectares and 32 hectares, respectively. In Camarines Sur, a 60-solar-panel irrigation pump amounting to 6 million pesos was installed in 2020. Our island is also a beneficiary of this modernization project. A 4-million irrigation project was completed last August 30, 2021, in Sablayan, Occidental Mindoro, covering 21.5 hectares of irrigated land that will benefit 13 farmers. Although numerous rice growers are now benefiting from these projects, this will not guarantee that they will serve every farmer's needs, especially those far from the facility. As such, inclusivity for all types of rice planters is imperative, especially for the marginal ones. An own-use irrigation pump might be the change needed to achieve sustainable water management goals. With all the expenses in rice farming and the unstable diesel price, investing in a new piece of agricultural machinery to solely consider the detrimental environmental effects of their old, GHG-producing diesel-powered pumps is impractical for the farmers given their socio-economic status.

Although there are various pieces of literature published on solar photovoltaic (PV) for irrigation [7, 8, 9, 10, 11], there are little to no known projects that utilize environmental and economic analyses to investigate the attractiveness of the investment in small-scale farming particularly for farmers that own, tenant, or share rice farmland limited to two hectares or less. Along with this premise, this study bridges this literature gap by evaluating the attractiveness of a more sustainable agricultural practice using solar PV over diesel-powered pumps for irrigating small-scale farmland in terms of environmental sustainability combined with economic feasibility and social acceptability. Specifically, this study aims to (1) analyze the economic feasibility shifting irrigation system from diesel-powered to solar pumps in terms of the net present value (NPV), returns on investment (ROI), and payback period (PBP); (2) evaluate the environmental impact in terms of reduced GHG emissions, avoidance of air pollutants (particulate matter 10, nitrogen oxide, sulfur oxide, and carbon monoxide), and energy savings; and (3) identify the social acceptability of solar PV irrigation system to small scale farmers.

2 Methodology

2.1 Research Locale

This study was conducted in the selected rice farming barangays of Calapan, the only city and the provincial capital of Oriental Mindoro. Calapan City is located in the northeastern part of the province and has a total land area of 26,520 hectares from which 8,100.70 hectares is allocated for rice farming. From this, 7,719.90 are irrigated while the remaining 380.80 are still rainfed [12]. From the 38 rice farming barangays, the areas chosen for this study are Managpi, Biga, Baruyan, Batino, Malad, Comunal, Sapul, Canubing I, Bayanan I, Nag-iba II, Patas, Balite, Tawagan, Tawiran and Bulusan as shown in Figure 1.

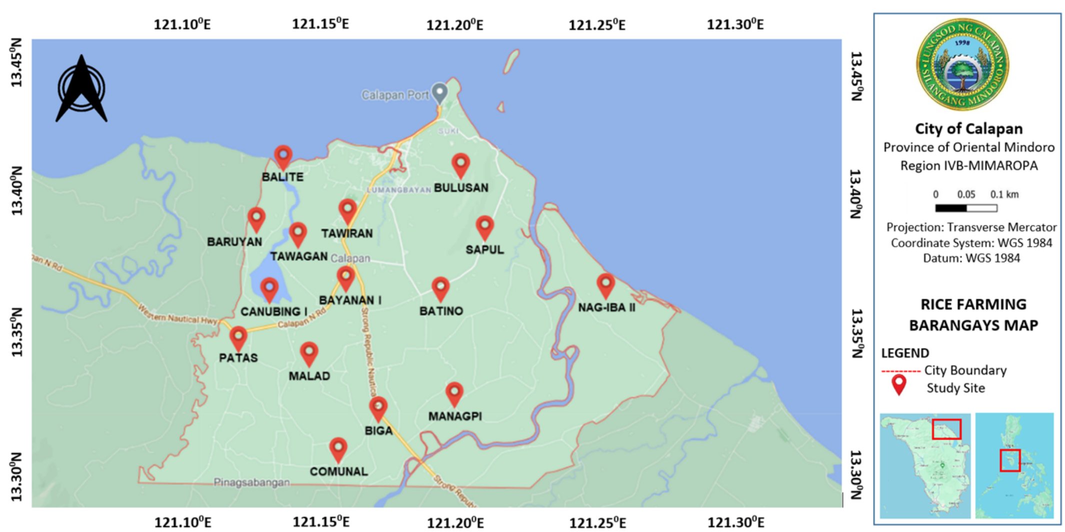

Figure 1.
Research Locale of the Study

With the current administration's support and City Agricultural Services, these barangays are maximizing their agricultural potential through projects such as the Angat Kabuhayan sa Agrikultura Program. In 2019, their joint efforts paid off as the Department of Agriculture awarded the city as the top rice producer city in MIMAROPA [13] and again in 2020 with 85,013.46 metric tons [12].

2.2 Respondents of the Study and Data Gathering

According to the data gathered from the City Agricultural Services, there are three types of irrigated rice farms in the city: irrigated by NIA and other governmental agencies, rain-fed, and privately pumped. However, since these areas are scattered depending on the farmers' topography, distance from the irrigation, and preference, they do not have an actual list of how many farmers are categorized in these groups. Therefore, the researcher opted to communicate directly with farmers and inquire about their availability for a quick survey.

The respondents of this study are 39 marginal farmers who own, tenants, or share two hectares or less of rice fields distributed among the 15 chosen rice farming barangays in Calapan City, Oriental Mindoro, as shown in Table 1. This study employed purposive sampling as criteria were set to deem a respondent qualified for the survey. Out of 62 barangays of Calapan City, 38 are classified as rice farming. These farming barangays were then ranked according to land area and were clustered into three: (1) large, (2) medium, and (3) small scale. Five barangays were randomly chosen from each cluster, and only then were farmers purposively sampled.

Table 1. Number of Respondents from the Rice Farming Barangays of Calapan City

Cluster	Barangay	Land Area (ha)	No. of Farmers
Cluster 1	Managpi	654	3
	Biga	509	4
	Baruyan	440	2
	Batino	427	3
	Malad	312	3
Cluster 2	Comunal	252	3
	Sapul	248	2
	Canubing I	193	3
	Bayanan I	130	2
	Nag-iba II	107	2
Cluster 3	Patas	86	4
	Balite	39	4
	Tawagan	37	1
	Tawiran	20	2
	Bulusan	5	1
		TOTAL:	39

The researcher utilized a self-made questionnaire adapted from the model of estimations of greenhouse gas emission factor, air pollutant factor, social acceptability, and economic valuation tools such as the returns on investment, payback period, and net present value [14, 15]. The adapted research instrument, which presents the questions in Tagalog, the vernacular of the local farmers, was validated by an economist and sustainable development planner, the Dean of Graduate School, and research panel members of Divine World College of Calapan Dean before the interview. Using the validated questionnaires, the researcher conducted a combination of face-to-face and virtual surveys using Google Forms. Minimum health protocols set by the Inter-Agency Task Force for the Management of Emerging Infectious Diseases were always observed. During the data gathering, a virtual survey was conducted for farmers with gadgets and stable internet connectivity to ensure less physical contact due to the high number of COVID cases in Calapan City. On the other hand, face-to-face surveys were conducted for those farmers with no means of virtual communication. On both occasions, the survey begins with a careful explanation of the study's nature, purpose, and other details before asking the actual questions. To gather the baseline data for the study and be able to compare it with alternative water management systems, the following data were gathered from the respondents:

(a) land area of rice field;

(b) initial investment cost of a diesel-powered irrigation system;

(c) operations (fuels) cost of diesel-powered irrigation system;

(d) maintenance and other costs of diesel-powered irrigation system; and

(e) farmer's preference for using solar vs diesel.

Furthermore, this study followed ethical considerations adhering to the Declaration of Helsinki on research with human subjects. The researcher explained to the farmers that the purpose of the study was solely for academics, obtained free prior informed consent from the respondents, ensured the anonymity of the participants, and guaranteed the confidentiality of the responses.

2.3 Data Analysis

2.3.1 Economic Analysis

The economic analysis focuses on the costs and benefits of investment in solar PV irrigation pumps from the perspective of small-scale farmers. Adopting the economic analysis employed in previous studies [14, 15], this research calculates the net present value (NPV), returns on investment (ROI), and payback period (PBP). Note that these tools were modified for the nature and type of investment at hand and were limited to the declared costs and benefits reported by the respondents. However, it does not involve seeking answers to issues involving solar irradiance, land availability, water availability, water abstraction, appropriate water quality, lack of skilled personnel for the design, and the codes and standards thereof.

ROI is a financial metric used to determine the probability of gaining from an investment. The ROI formula is described in Equation 1

$$ROI = \frac{\sum_{t=1}^{T} R_t}{I} * 100\% \tag{1}$$

where R_t is the annual net cash flow or the value of energy savings from shifting to solar PV at valuation period t, which is equal to the difference between the average annual cost of operating the irrigation using diesel and solar PV, T is the technical lifetime of solar PV, and I is the investment cost for solar PV.

For R_t, the annual cash flow for each technology is equal to the marginal turn-over minus marginal cost. It is assumed that both technologies produce the same quantity of water needed to irrigate one hectare of farm. It can also be assumed that there are the same intervening variables such as rice production, labor, fertilizer, weather patterns, and planting periods, among others. Therefore, both technologies have the same turn-overs but only differ in variable cost which is equal to the amount of diesel needed to sufficiently irrigate the farm. Meanwhile, for the investment cost for solar PV (I), it is assumed that the farmers are already using diesel-powered irrigation pumps. Therefore, its investment cost is accounted for in this study. For all economic analyses, the investment cost is the cost of capital for the solar PV system and its installation.

PBP is the amount it takes to recover the cost of the initial investment in a solar powered-irrigation pump. It is equal to the cost of the investment divided by the annual net cashflow, as described in Equation 2.

$$PBP = \frac{I}{\sum_{t=1}^{T_i} R_t} \tag{2}$$

NPV of the project is the value of all future cash flows over the entire life (T) of solar PV irrigation pump operation discounted to the present period at a discount rate of (r), which is described in Equation 3.

$$NPV = \sum_{t=1}^{T} \frac{R_t}{(1+r)^t} - I \tag{3}$$

The following are the assumptions for the calculation of different economic tools:

Investment costs of solar PV irrigation system are the total initial expenditures on solar panels, pump, and installation.

Investment costs of solar PV irrigation systems are the total initial expenditures on pumps and installation.

Operations and maintenance costs for solar PV irrigation systems are the annual expenses in maintenance, labor, and other expenses.

Operations and maintenance costs for diesel-powered irrigation systems are the annual expenses in fuel (diesel), maintenance, labor, and other expenses

2.3.2 Environmental Analysis

While various studies provide methods for different forms of environmental analysis, this study only focuses on calculating the environmental impact of the combustion of diesel fuel for irrigation. This estimates the GHG and air pollutant emissions adapted from previous studies [15] and emission factors from the U.S. Environmental Protection Agency (EPA) [16], Asian Development Bank (ADB) [17], and Department of Climate Change, Energy, the Environment and Water of Australia (DCCEEW) [18]. This study, however, does not include the "cradle-to-grave" emissions of the irrigation systems or emissions produced during its production, installation, and/or maintenance, and even disposal. To calculate the GHG emissions for using diesel-powered irrigation pumps, the average annual fuel consumption (FC) was multiplied by the emission factor (EF) or its CO_2 equivalent as described in the equation below:

To calculate the GHG emissions for using diesel-powered irrigation pumps, the average annual fuel consumption (FC) was multiplied by the emission factor (EF) or its CO_2 equivalent as described in Equation 4.

$$GHG = FC * EF \tag{4}$$

For this study, FC is equal to the average liters of diesel used for irrigation in all cropping seasons of the year while the EF will be obtained from the Emission Factors for Greenhouse Gas Inventories as declared by EPA, ADB, and DCCEEW.

For the calculation of air pollutant emissions, the average annual fuel consumption and pollutant factor were multiplied as shown in Equation 5

$$AP_i = FC * PF_i \tag{5}$$

where AP is the air pollutant emission factor, i is the air pollutant being tested: CO, NOx, SOx, and PM, FC is the fuel consumption, and PF is the pollutant factor.

2.3.3 Social Acceptability

The last part of the analysis includes the evaluation of the social acceptability of the adoption of solar PV irrigation systems. In this analysis, the percentages are calculated to identify how many farmers are willing to shift their agricultural practices from using diesel-based irrigation to solar PV systems. This is followed by the narratives of small-scale farmers that support their choice of technology. Narrative analysis was used to interpret the detailed lived experiences obtained from the interviews of farmers, which sought to preserve the integrity of their personal experiences that cannot adequately be understood in terms of their discrete values [19].

3 Results and Discussion

3.1 Parameter Estimation Using Diesel and Solar PV Irrigation Systems

Table 2 summarizes the parameter estimations based on the survey conducted in 15 farming barangays of Calapan City with 39 marginalized farmers who use diesel-powered irrigation systems. The average investment cost for this traditional irrigation system is PHP 28,846 per hectare with a minimum of PHP 7,500, a maximum of PHP 140,000, and a standard deviation (SD) of PHP 25,278. This amount includes the price of the diesel-powered generator, water pump, excavation for the water source, installation costs, and the organized structure to protect the machinery from extreme weather conditions.

Table 2. Parameter Estimation of Diesel-powered Irrigation System

Parameter	Unit	Mean	SD	Minimum	Maximum
Investment Cost	Php/ha	28,846	25,278	7,500	140,000
Diesel Consumption	L/ha/yr	74.55	79.48	11.36	378.54
Fuel Cost	Php/ha/yr	19,693	20,996	3,000	100,000
Maintenance and Other Operational Costs	Php/ha/yr	23,754	54,174	2,500	300,000

There are two types of cropping cycle practice in the city: the 3-season cycle for crops grown and harvested for 120 days and a 2-season cycle for crops harvested after 150 days. The farmer's fuel consumption depends on the amount of water the crops need, which is affected by different factors. Results show that, on average, each farmer uses 74.55 liters of diesel per hectare in all cropping seasons of the year at a minimum of 11.36 liters, a maximum of 378.54 liters, and an SD of 11.36. This variability occurs due to the proximity to the NIA irrigation system, weather conditions, the difference in the distance from the water source (either surface or borewell), topography, and the pump's efficiency. With this, each farmer allocates an average of PHP 19,693 for fuel costs, with the lowest at PHP 3,000 and PHP 100,000 per hectare yearly with an SD of PHP 20,936, not to mention the other costs for operational and maintenance that could reach up to PHP 23,754 per hectare annually.

The survey conducted mainly asked the farmers about their usual operational costs in terms of the fuel consumption of diesel-powered irrigation systems, but about half of the time, the respondents start with *"depende kasi sa presyuhan ng krudo"* (it depends upon the current price of diesel) before they give their annual fuel expenditures. This statement and the data mentioned above align with the literature that explores the disadvantages of dependence on diesel as a source of energy. The price of diesel is dependent on global crude oil demand. Its retail price is affected by different factors such as the costs of the crude oil purchased by refineries, the profits from the refining process, distribution, marketing, retail station costs, taxes, and various types of uncertainties [20, 21, 22]. Since the Philippines outsources 85% of its fuel from the Middle East and the remaining 15% from ASEAN countries, its price constantly differs as influenced by the current demand. With 36 hours of continuous irrigation at least once a week, especially at the beginning of the cropping season, and while considering the rice paddy area, depth of water, and extreme weather conditions, the farmers highly spend the operational costs for the water irrigation of their crops.

Compared to diesel, a solar-powered irrigation system costs PHP 105,000 per hectare in initial investment and PHP 7,000 for its maintenance and operational costs as shown in Table 3. On the other hand, Table 4 presents the specifications and prices for a solar-powered submersible water pump from a major distributor and retailer of solar energy products intended to irrigate a rice field.

Table 3. Parameter Estimation of Solar-powered Irrigation System

Parameter	Unit	Mean	SD	Minimum	Maximum
Investment Cost	Php/ha	105,000	NA	90,000	120,000
Maintenance and Other Operational Costs	Php/ha/yr	7,000	NA	5,000	9,000

The solar pump has no operational costs as it runs on energy from the sun. Conversely, the maintenance cost accounts for the replacement costs of a submersible water pump that needs to be replaced in 8 to 15 years, depending on the siltation and quality of the water source. The solar panel needs no maintenance except for the constant cleaning of the panels to ensure maximum capture of sunlight.

Table 4. Retail Price of the Solar-powered Irrigation Pump

Solar-powered Irrigation System – Php180,000 including labor costs Specifications: 3hp intended for 2-3 hectares, water output - 19m^3/h, max head - 60m	
Unit	**Cost**
Pump and Controller	Php 49,000
Solar Panel	Php 70,000
Accessories	Php 30,000
Grounding	Php 2,500
PV Cable	Php180 per meter
Mounting Structure – Php 30,000 including labor costs	
Materials (Pipe, concrete, accessories)	Php 20,000
Labor costs*	Php 10,000

**Scope of work includes excavation of foundation, concreting, and steal works (cutting and welding of pipes)*

Studies employing various methods and models have proven solar PV's effectiveness in pumping water for irrigation and other purposes [23, 24, 25]. However, these papers also highlight that the most common disadvantage of solar irrigation is its high initial investment cost. While the data gathered in this research confirms that solar irrigation is 264% more expensive than its diesel counterpart, its operational and maintenance cost is relatively lower at 239% per hectare annually. This means that for the 25 years of its operation, a farmer could save up to PHP 418,850 per hectare on maintenance costs.

Several financial investment and business models offer different options for solar irrigation, such as the ones practiced for small-holder solar pump-based irrigation in Ethiopia [26], in sub-Saharan Africa [27], and in other developing countries across the Middle East, North Africa, and Southeast Asia [28]. When farmers unite in using solar irrigation as a group-based system like the ones established by the Department of Agriculture in Occidental Mindoro and other agricultural provinces, they can finance and cover the initial capital investment of the solar irrigation system. This setup will allow them to share costs and risks and foster the act of sharing valuable information, knowledge, and skills on a more sustainable way of rice farming [29].

3.2 Economic Analysis of Diesel and Solar PV Irrigation Systems

Table 5 summarizes the results of the economic analysis between diesel-powered and solar-powered irrigation pumps. The results show that for every hectare, a farmer can save an average of PHP 19,693 in the cost of diesel annually. This amount could be used to regain the high investment cost of the solar irrigation system or be invested in other technologies or systems that promote sustainable farming.

Table 5. Economic Analysis of Solar-Powered Irrigation System

Economic Indicators	Unit	Value
Diesel Cost Savings	Php/ha/yr	19,693
Payback Period	Years	8.27
Return on Investment		110%
Net Present Value	Php/ha	10,214

Despite the high investment cost, results reveal the best investment opportunity for a solar irrigation system with PHP 10,214 NPV for 25 years of operation. Implementing the solar irrigation project increases the discounted worth of the investment by PHP 10,214/ha, more than the current value of the asset.

In terms of the PBP, the results show that the investment made in solar PV irrigation is recoverable after 8.27 years of operation. The PBP may seem long considering the amount of initial investment made by the farmer. Still, it should be noted that this value is exclusive to using solar panels for irrigation purposes only. Since the Philippines is located just above the equator and has a good solar irradiance at 128-2,032/m2, which is equivalent to 4.5 – 5.5 kWh a day [30], and irrigation is not year-round, excess solar energy could be generated, which can be shared or used for other purposes [10] and eventually shorten the PBP.

Lastly, ROI directly measured the revenue of solar PV irrigation systems against the diesel-powered irrigation system. Results show a return of up to 2 times the initial investment in 25 years of operation. With a 110% return on investment, it suggests that while the initial cost may be high for small-scale farmers at PHP 110,000 per hectare, this amount will be covered and doubled in the effective lifetime of the solar PV system. This supports previous studies that, considering the full life cycle of an irrigation system, solar PV-powered systems are economically viable and profitable alternatives over diesel-powered systems [23, 31, 32]. Additionally, decreasing prices for PV panels due to higher demand and technology learning and the increasing and stochastic diesel prices [30, 33] may further improve the cost-effectiveness of solar PV irrigation systems.

3.3 Environmental Impacts of Diesel-based and Solar PV Irrigation Systems

This study estimated the environmental impact of the technology investment by calculating the amount of pollution avoided and GHG emission reduction from shifting irrigation systems from diesel to solar PV as summarized in Table 6. The result shows that the amount of GHG emissions produced by diesel for stationary energy purposes is about 200 Kg CO_2 eq/ha/yr. When farmers decide to invest in an own-use solar-powered irrigation system, this is equivalent to reducing GHG emissions. To better visualize the extent of this amount, a typical adult tree can absorb around 21 Kg of CO_2 per year. Over a lifetime of 100 years, one tree could absorb around a ton of CO_2. Results imply that the GHG emission reduction from shifting diesel irrigation to a solar PV system from a 5-hectare rice field in one year is equivalent to CO_2 absorbed by a tree for 100 years. Furthermore, this result implies a significant decrease in GHG emissions from the agriculture sector, currently at 16% of the total and second-highest after the transportation sector.

Table 6. Environmental Analysis of Diesel-powered Irrigation System

Environmental Indicators	Unit	Value
GHG Emission Reduction	Kg CO_2 eq/ha/yr	199.78
Avoided Air Pollutant Emissions:		
Particulate Matter	g/ha/yr	14.91
Nitrogen Oxides	g/ha/yr	2.98
Sulfur Oxides	g/ha/yr	193.82
Carbon Monoxide	g/ha/yr	149.09
Diesel Demand Savings	L/ha/yr	74.55

Note: Emission Factors for GHG Emission (2.68 kg CO2 eq/L), particulate matter (2 g/L), nitrogen oxides (0.2 g/L), sulfur oxides (0.04 g/L), and carbon monoxide (2.6 g/L).

Despite the many advantages of diesel-powered generators, like high efficiency, durability, and low operating costs, this technology is one of the significant contributors to environmental pollution and several health problems. The combustion of diesel to produce energy produces harmful pollutants such as particulate matter, nitrogen oxide, sulfur oxide, and carbon monoxide [34].

As shown in Table 6, results demonstrate the significant volume of pollutants avoided in shifting to solar-powered irrigation. Particulate matter, the particle residue from incomplete fuel combustion ranging from 2.5-10 microns, rendered 14.921 grams per hectare annually. This infers the extent of the avoided fine particles that may penetrate the respiratory and circulatory system and cause severe damage to the heart, brain, and lungs [34]. Another study claims that PM is also linked to stroke, type 2 diabetes, and loss of cognitive function [35]. With a total land area of 47 hectares, assuming all respondent farmers will shift to solar PV, a total of 175.43 Kg of particulate matter will be avoided in 25 years. Results further show that 2.98 g/ha/yr of nitrogen oxides, which includes nitrogen dioxide, nitric oxide, nitrous acid, and nitric acid, will be avoided as well as the severe health risks from the exposure such as heart ailments, stroke, chronic obstructive pulmonary disease, and lung cancer [36].

On the other hand, sulfur oxides, an air pollutant from the combustion of fuels containing sulfur, will be avoided at 193.82 grams per hectare annually. This pollutant often causes cardiac and respiratory issues and or damage to skin, eyes, and mucous membranes [37, 38]. Furthermore, computations reveal that the current water management system yields 149.09 g/ha/yr of carbon monoxide, a toxic colorless, odorless gas obtained from the incomplete burning of fossil fuels. Inhalation or exposure to this poisonous gas may impede oxygen to vital organs as this gas attaches to hemoglobin. As a result, it severely diminishes the amount of oxygen that reaches these organs and may eventually lead to serious damage or death [34].

Lastly, results show that a farmer could save 74.55 liters of diesel per hectare annually after shifting to a solar PV system. Energy consumption for the water management of the agricultural sector may seem small. Still, if local farmers adopt self-use solar irrigation for small-scale farming, this would imply a potential reduction in diesel demand if implemented on a large scale.

3.4 Social Acceptability of Solar PV Irrigation System

Figure 2 below shows the percentage of farmers who are willing and unwilling to invest in a self-used solar irrigation system. Out of 39 respondents, 69% or 27 showed their willingness to invest, 26% or 10 respondents declined, while 5% or two respondents would postpone their investment. Among those respondents who agree or are willing to buy/invest in a new system, most of the reasons are bigger savings, less fuel consumption, and machine efficiency.

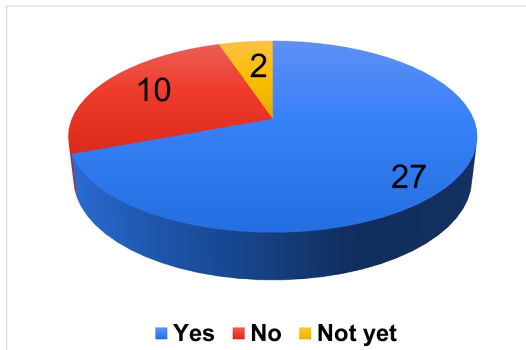

Figure 2.
Respondent's Willingness to Invest in a Solar-powered Irrigation System

The primary reason for the farmers' willingness to purchase their own solar irrigation system is that they do not have to constantly buy diesel. Hence, this will allow them to save fuel costs and other maintenance related to its purchase, such as labor and transportation. For instance, respondent F25 mentioned that, *"Oo, dahil mas makakatipid ako pag ang gamit na ay solar sa pagpapatubig at maaaring pangmatagalan na ang solar na magagamit. Hindi na lagi bibili ng krudo para sa pagpapatubig."* (Yes, because I can save if I use solar in irrigating [my rice field] and I can use it for a long time hence I will not have to buy diesel for irrigation anymore.) Similar response was given by F16, *"Oo naman, dahil kung doon ako makakatipid at magagamit ko ng matagal mas maigi 'yon."* (Definitely yes, if [SPIS] can allow me to save and I can use for a long time, that is better). Existing literature supports this by explaining how the shift from solar-powered irrigation systems can significantly save all operational costs from buying diesel to power the water pumps. According to Hilarydoss [39], solar pumping is a more promising alternative to address the issues of increasing fuel costs and strict emission laws in developing countries. Although there are some limitations to this technology like high capital costs, other technical aspects such as high head water pumping, batteries or huge storage reservoirs, and environmental aspects like ambient temperature, solar radiation intensity, wind speed, dust collection, and minimum annual rainfall, still, the advantages of solar PV pumping outweigh these cons. However, unlike the countries involved in the study mentioned above, the Philippines receives higher solar irradiance that can be translated to a power generating capacity of 4.5 to 5.5 kWh/m2 in 24 hours [30], which can sustain a solar PV system to irrigate a rice field. Moreover, results showed that the willingness of some farmers complemented their awareness of the advantages of owning a solar PV system, which included a longer life cycle, no noise pollution, and its potential to be automated or accessed remotely. This supports the previous claim on acceptance of solar irrigation among the rural farmers of Pakistan, which states that aside from gender and age, the main factors affecting their acceptance are education, awareness, ease of use, and usefulness [40].

Some farmers are willing but quite hesitant as they are not fully informed of the technology, its use, and its benefits. Aside from its price, their common concern revolve around the number of years that it will last, and its efficiency compared to diesel-powered pumps. For instance, F1 mentioned, *"Oo, interesado akong bumili. Ngunit sa aking palagay ay masyadong mahal ang halaga at hindi ko alam kung gaano katagal ang itatagal ng solar water pump sapagkat kung ito ay tatagal ng mga 5 hanggang 10 taon lamang mas pipiliin ko pa na gamitin ang aking water pump na de krudo dahil iyon ay ginagamit ko na ng 18 taon."* (Yes, I am interested in buying [SPIS]. However, in my opinion, a solar water pump is too expensive, and I am not aware of how long it will last. If it only lasts from 5-10 years, I still prefer to use my diesel-powered pump, which I have been using for 18 years). Another farmer (F32) said, *"Oo, kung ito ay kasing husay ng de krudo."* (Yes, if it is as efficient as diesel-powered pumps). This supports previous claim [41], which listed perceived benefit and compatibility as the top reasons for the intention to use solar power pumps. These results would play a significant role in understanding the barriers and other challenges that hinder the adoption of solar irrigation among marginal farmers. Hence, proper information dissemination is needed to make the farmers more aware of this technology's nature, costs, advantages, and disadvantages to better help them make informed decisions on its adoption [14, 42].

On the other hand, most farmers who declined the adoption of solar irrigation know its benefits but refused, mainly because of the expensive investment. Given the small land area of their rice farm and the small profit from it, they deemed it impractical to invest in a solar-powered pump. One of the respondents (F17) said, *"Pero kapag po maliit lang ang binubukid katulad po noong sa amin, malaki lang po magagastos. Mas maganda po siya sa malalaking palayan na sukat ay isang ektarya o higit pa."* (If the tilled land area is limited just like ours, it will cost us a great deal. SPIS is more appropriate for rice farms that are 1 hectare or more). Others say they are already used to this technology and most likely would stay using it due to familiarity. At the same time, some rely alternately on the NIA irrigation and rain and only use pumps during summer. This is one of the reasons why research on small-scale farming like this should be conducted. There are limited studies, especially in developing countries that discuss the economic feasibility of small investments due to apparent unfavorable results.

Lastly, one of the two respondents (F8) who will postpone the investment in solar irrigation systems said that they just bought their diesel pumps and will wait until they need replacement. The other respondent (F28) would want to wait until he is sure it is as efficient as diesel pumping water.

Notably, no farmer gave a reason related to the benefits of solar irrigation to the environment, including the potential to lessen air pollution, alleviate global warming problems, or even its health benefits. No one also mentioned its potential to increase their farms' output and, by extension, their income, and a potential poverty reduction. This dramatically reflects their limited awareness of sustainability and the full benefits of this technology for financial gain and the environment. Comparably, studies in Pakistan [43] and Africa [44] showed that farmers are aware of the prevailing temperature and rainfall patterns. However, they do not have an in-depth awareness of the environmental impacts associated with agriculture. More importantly, their results are similar as the paper indicated that in the sustainable development model, the farmers displayed more financial sustainability than environmental or social sustainability. In this regard, governmental agencies and other private institutions related to the environment, energy, and agriculture can work hand in hand to spread awareness of climate change and sustainable rice production in the country.

4 Conclusion and Recommendations

A human ecological perspective of sustainable farming using solar irrigation systems recognizes the interconnectedness of agriculture, energy use, and the environment. Using renewable energy benefits the community by enhancing food security, economic well-being, and ecological sustainability, while reducing agriculture's negative impact on local ecosystems and the global environment. This study analyzed the feasibility of shifting irrigation systems from fossil fuels to renewable energy to realize these benefits. The novelty of this study highlights the perspective of financially disadvantaged farmers of small-scale farms in Calapan City, Oriental Mindoro. It analyzes the economic attractiveness, environmental impact, and social acceptability of shifting irrigation technology from diesel-powered to solar pump systems.

Parameter estimation showed that solar irrigation systems are more expensive than their diesel counterpart in terms of initial investment. However, its maintenance and operational costs are relatively lower. Hence, farmers could save on fuel costs for the rest of their lives. Given the volume of diesel used by farmers per hectare, results demonstrated that by shifting to solar PV, a significant amount of carbon dioxide and other air pollutants could be kept from interspersing in the air. Using the volume of agricultural consumption of diesel and the country's annual fuel demand, shifting to solar PV systems to irrigate rice farms can significantly increase the energy savings of the agricultural sector. Economic valuation tools indicated that the proposed system is a good investment with its positive Net Present Value, profitable Returns on Investment, and relatively short Payback Period. Furthermore, most small-scale farmers were interested in investing in solar PV irrigation systems. While the financial aspect of investing in irrigation systems was high, the in-depth awareness of environmental sustainability was low.

The findings of this study provide recommendations for the widespread adoption of a more sustainable irrigation system and directions for future research. First, farmers should be informed about the environmental benefits of shifting irrigation systems from technologies based on fossil fuels to renewable energy sources. Since the initial investment for solar PV technology is relatively costly from the perspective of small-scale farmers, subsidies, and other financial schemes should be provided to these groups of farmers. Further studies should be conducted to complement the current socio-economic and environmental analyses by integrating the legal and policy support, technical aspects of solar PV irrigation systems, and social acceptability from other stakeholders. Another limitation of the study is the limited number of small-scale farmers interviewed during the pandemic. Future studies should increase the number of respondents to better capture the social acceptability and perceived impacts of shifting to solar irrigation systems. Despite these limitations, this study serves as a good benchmark for further analysis of the adoption of more human ecologically sustainable farming practices in the Philippines and other agricultural countries.

Nomenclature

Symbol/ Variable	Description
ROI	Returns on investment
NPV	Net present value
PBP	Payback period
R_t	Annual cash flow, energy cost savings
t	Valuation period, year
T	Technical lifetime of solar PV
I	Investment cost
r	Discount rate
GHG	Greenhouse gas emissions
AP_i	Air pollutant emission
i	Air pollutant (CO, NOx, Sox, PM)
FC	Fuel consumption
EF	Emission factor
PF_i	Pollutant factor

Statements and Declarations

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Conflicts of Interest

The author declares no conflict of interest.

Data Availability

Data is available upon request from the author.

Ethical Considerations

This study followed ethical considerations adhering to the Declaration of Helsinki on research with human subjects. The researcher explained to the farmers that the purpose of the study was solely for academic purposes, obtained free prior informed consent from the respondents, ensured the anonymity of the participants, and guaranteed the confidentiality of the responses.

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